Soil & Tillage Research, 4 (1984) 79—91
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

PLANT NUTRIENT LOSSES IN RUNOFF FROM CONSERVATION TILLAGE CORN*

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(Accepted 4 May 1983)

ABSTRACT

McDowell, L.L. and McGregor, K.C., 1984. Plant nutrient losses in runoff from conservation tillage corn. *Soil Tillage Res.*, 4: 79—91.

Conservation tillage in north Mississippi, U.S.A., reduced total (sum of solution and sediment) plant nutrient losses in runoff from corn, even though solution nitrogen (N) and phosphorus (P) concentrations in runoff were greater than from conventional-till and sediments were enriched severalfold in N and P. Plant nutrient losses were reduced by conservation tillage because of the significant reductions in soil loss. Soil losses from corn grown for grain were reduced more than 92% by reduced and no-till practices. Corresponding total losses of N and P were reduced about 70 and 80%, respectively.

Conservation tillage reduced plant nutrient losses associated with sediments but increased solution P concentrations and losses in runoff. Solution P concentrations and losses, which were related to crop management, decreased in the following order: no-till corn (grain) ⩾ no-till corn (sillage) > reduced-till corn (grain) > conventional-till corn (grain) > conventional-till corn (silage). Solution P concentrations and losses in runoff increased with an increase in crop residues left on the soil surface after harvest and with a decrease in annual soil loss.

INTRODUCTION

Conservation tillage, which leaves all or part of the previous years' crop residues on the soil surface, effectively controls soil erosion. Studies concerned with the effectiveness of conservation tillage in controlling the loss of plant nutrients from cropland indicate that the total (sum of solution and sediment) plant nutrient loss decreases if conservation tillage is used, but that solution phase nutrient concentrations, particularly phosphorus (P), may be high in runoff from no-till cropland, when the sediment concentration is low (Barrows and Kilmer, 1963; Holt et al., 1973; Schuman et al., 1973; Burwell et al., 1975). Recent studies in Iowa and Mississippi indicated that losses of dissolved nitrogen (N) and P may be greater with conservation

*In cooperation with the Mississippi Agricultural and Forestry Experiment Station.

tillage than with conventional tillage. The increased losses were attributed to the combined effects of increased crop residue cover, decreased fertilizer incorporation, and decreased soil loss (Johnson et al., 1979; McDowell and McGregor, 1980).

Surface application of fertilizer is a common practice in conservation-tillage crop production. When fertilizer is not incorporated into the soil, however, the amounts of soluble nutrients measured in runoff increase (Römkens et al., 1973; Timmons et al., 1973; Smith et al., 1974; Whitaker et al., 1978).

This study is a continuation of research reported earlier on no-till soybeans (McDowell and McGregor, 1980). The objectives of this study were to determine (1) the N and P concentrations and losses in runoff and sediments from conventional, reduced, and no-till corn grown for silage and grain, (2) the mode of chemical transport, i.e. the partitioning of N and P between water and sediment, and (3) the effect of crop residues left on the soil surface on solution P concentrations and losses in runoff. Comparison of solution N and P concentrations and losses in runoff from silage and grain plots should provide additional information on the contribution of crop residues to N and P losses. This information is needed to develop best management practices for nonpoint pollution control and to develop and verify models for predicting sediment and plant nutrient losses.

EXPERIMENTAL PROCEDURE

Runoff and soil-loss measurements were initiated in 1974 on 0.01-ha plots (5% slope) at the North Mississippi Agricultural and Forestry Experiment Station, Holly Springs, MS, U.S.A. Each plot was 4 m wide × 22.1 m long in slope length. Plant nutrient data are reported for the 1975—1977 water years (WY) (October 1—September 30). Five plots were duplicated as follows:

1. Conventional-till corn for silage (C-SIL).
2. Conventional-till corn for grain (C-GR).
3. Reduced-till corn for grain (planted no-till but followed by two cultivations during the growing season) (R-GR).
4. No-till corn for silage (N-SIL).
5. No-till corn for grain (N-GR).

The soil was a Providence silt loam (Typic Fragiudalfs) of loessial origin, underlain by coastal plain sands. Plots were equipped with FW-1 water level recorders, H-flumes and N-1 Coshocton-type wheel sampling devices (Carter and Parsons, 1967). Runoff volume was measured after each rainstorm. Soil and plant nutrient losses were computed from runoff volumes and sediment and nutrient concentrations as determined from aliquot samples of runoff. Samples were collected after each storm, or in some instances, after a small group of storms. Details of the rainfall, runoff, and soil-loss relationships have been reported (McGregor and Greer, 1982).

For all tillage practices, corn was planted in rows 1 m apart up and down the slope in April of each year. Recommended crop variaties, plant populations, planting dates, and fertilization rates were used for each treatment. Ammonium nitrate (34% N), superphosphate (45% P_2O_5), and muriate of potash (60% K_2O) were blended and applied at planting; the remaining N (101 kg/ha) was surface-applied as sidedressed urea (45% N) in late May or early June (Table I). Crop residues were chopped and left on the ground after harvest for all tillage practices.

TABLE I

Tillage practices and fertilizer application rates for corn tillage studies (1975, 1976, and 1977 water years)

Plot	Fertilizer (kg/ha)								
	1975			1976			1977		
	N[a]	P[b]	K[c]	N[a]	P[b]	K[c]	N[a]	P[b]	K[c]
C-SIL	167	23	45	170	30	58	165	28	53
C-GR	169	8	15	170	30	58	165	28	53
R-GR	189	0	28	170	30	58	165	28	53
N-SIL	189	15	0	170	30	58	165	28	53
N-GR	189	7	0	170	30	58	165	28	53

[a]Ammonium nitrate was applied at planting; 101 kg N/ha was surface-applied as sidedressed urea.
[b]Superphosphate (45% P_2O_5).
[c]Muriate of potash (60% K_2O).

Conventional-till seedbed preparation included moldboard plowing, disk-harrowing, spike-tooth harrowing, and bedding. Moldboard tillage began just before planting; therefore, there was essentially no fallow period as there often is in conventional tillage. Plots were cultivated as needed during the growing season.

A no-till planter was used for all tillage practices. A fluted coulter followed by a small chisel cut through any surface residues and opened a slot in the soil about 100—130 mm deep for fertilizer and seed. Fertilizer, placed in the bottom of the slot, was covered and separated from the corn seeds by a layer of soil about 50—75 mm deep. A press wheel closed the slot opening. With this method of fertilizer placement, the pollution potential of fertilizer elements in runoff was probably less than with the double-disk opener used in the previous study (McDowell and McGregor, 1980), which did not always cut sufficiently deep into the soil. The fluted coulter also provided the increased soil pulverization needed for soil—seed contact and reduced clod formation by the chisel.

In the no-till system, grasses and weeds were controlled during the cropping season by preemergence broadcast application of herbicides and by postemergence spot applications of herbicides. The reduced-till system was the same as no-till, except that postemergence applications of herbicides were replaced with two cultivations during the early growing season. The N-SIL plots were omitted from the study during the 1977 WY. Those plots were fallowed in 1977 to help control bermudagrass infestation.

All no-till and reduced-till plots had been in continuous no-till since 1970 (McGregor, 1978; McDowell and McGregor, 1980). The C-SIL plots were in no-till soybeans during 1970—1973, but the C-GR plots were in conventional-till soybeans during that period.

Runoff samples from the plots were refrigerated at 4°C and subsequently analyzed for sediment (McDowell et al., 1981) and nutrient concentrations. Samples were filtered [0.45 micrometer (μm) pore size] to separate sediment from solution. Sediment was dried overnight at 105°C and weighed to determine sediment concentration. The filtrate was analyzed for ammonium-nitrogen (NH_4-N) by the automated colorimetric phenate method (Technicon, 1973a) and for soluble inorganic P by the automated colorimetric phosphomolybdenum blue method (Technicon, 1973b). Nitrate-nitrogen (NO_3-N) in the filtrate was determined by a modified procedure of Wood et al. (1967) and Strickland and Parsons (1968), in which NO_3-N is reduced to nitrite-nitrogen (NO_2-N) by a cadmium column. Soils and sediments were analyzed for total Kjeldahl nitrogen (*TKN*) by the automated ammonia-salicylate method (Technicon, 1974a) and for sediment total P (*STP*) by the automated phosphomolybdenum blue method (Technicon, 1974b) after digestion with a mixture of HgO, H_2SO_4, and K_2SO_4.

The Kolmogorov—Smirnov two-sample test statistic (T_1) as described by Conover (1971) was used to test the null hypothesis that there was no significant difference in chemical concentration and loss distribution functions of storm runoff for the different management practices. T_1 is the greatest vertical distance between two empirical cumulative distribution functions.

RESULTS AND DISCUSSION

Rainfall, runoff, and soil loss

Rainfall was 1424, 1299, and 994 mm in the 1975, 1976, and 1977 WY, respectively, as compared with a 12-year average (1963—1974) of 1321 mm. The annual erosivity index (*EI*)* was 6130, 6960, and 3810 MJ · mm/ha · hour · year in 1975, 1976, and 1977, respectively, as compared with the 12-year average (1963—1974) of 6960 MJ · mm/ha · hour · year (McGregor and Mutchler, 1977).

No-till and reduced-till practices were effective in controlling erosion (Table II). The 3-year average soil losses decreased in the following order:

*For the purpose of computing *EI* in this study, a storm was defined as precipitation of at least 13 mm without a 6-h break.

C-SIL > C-GR ≫ R-GR > N-SIL = N-GR. Average soil losses from no-till were only 3—4% of that from conventional-till. The effect of cropping history on soil losses is considered to be minimal because soil loss differences between conventional and conservation-till differed by an order of magnitude.

TABLE II

Annual runoff and soil loss in corn tillage studies for 1975, 1976, and 1977 water years

Plot	1975		1976		1977		Average	
	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)
C-SIL	534	29.89	400	24.76	290	17.54	408	24.06
C-GR	460	21.61	390	23.81	268	7.20	373	17.54
R-GR	287	1.72	197	1.62	134	0.96	206	1.43
N-SIL	320	0.85	197	0.64	[a]	[a]	259	0.75
N-GR	460	0.81	320	0.82	204	0.72	328	0.78

[a]Fallowed in 1977 water year; 2-year average listed.

Plant nutrient concentrations and losses

Solution N (NH_4-N + NO_3-N) concentrations (discharge-weighted) in runoff were significantly greater (0.01 level) from conservation tillage than from conventional tillage (Table III). NO_3-N concentrations and losses in runoff from conservation tillage were significantly greater at the 0.01 and 0.05 levels, respectively, than from conventional tillage (Tables III and IV). NO_3-N concentrations and losses in runoff from C-SIL and C-GR were not significantly different at the 0.2 level. Concentrations and losses in runoff from R-GR, N-SIL, and N-GR were not significantly different at the 0.1 level. Annual solution N losses from all plots were relatively low, with a maximum of only 8 kg/ha measured in runoff from R-GR in 1976 (Table V).

The 3-year average solution P concentrations (discharge-weighted) and losses in runoff were significantly greater (0.01 level) from conservation tillage than from conventional tillage, and decreased in the order: N-GR ⩾ N-SIL > R-GR > C-GR > C-SIL (Tables III and VI). Solution P concentrations from N-SIL and N-GR were 0.291 and 0.363 mg/l, respectively, compared with 0.027 and 0.083 mg/l from C-SIL and C-GR, respectively (Table III). These higher concentrations and losses in runoff from conservation tillage were attributed to release of P from crop residues (McDowell et al., 1980) and to insufficient sediment to sorb P from solution. The effect of fertilizer placement was considered minimal because the no-till planter, which was used for both conventional and conservation-tillage, incorporated the fertilizer very effectively. Annual solution P concentrations (C) in runoff

TABLE III

Annual discharge-weighted solution N and P concentrations (mg/l) in runoff from corn tillage studies (1975, 1976, and 1977 water years)

Plot	1975			1976			1977			Average		
	NH_4-N	NO_3-N	P	NH_4-N	NO_3-N	P	NH_4-N	NO_3-N	P	NH_4-N	NO_3-N	P
C-SIL	0.25	0.54	0.017	0.36	1.76	0.050	0.36	0.57	0.015	0.31	0.43	0.027
C-GR	0.24	0.44	0.071	0.59	2.82	0.111	0.48	0.90	0.064	0.42	0.50	0.083
R-GR	0.34	1.23	0.165	0.77	3.29	0.368	0.70	1.92	0.204	0.56	2.03	0.238
N-SIL	0.28	1.07	0.232	0.70	2.79	0.389	[a]	[a]	[a]	0.44	1.72	0.291
N-GR	0.29	1.03	0.232	0.57	3.31	0.570	0.65	1.71	0.334	0.46	0.94	0.363

[a]Fallowed in 1977 water year; 2-year average listed.

TABLE IV

Annual NH_4-N and NO_3-N losses (kg/ha) in runoff from corn tillage studies (1975, 1976, and 1977 water years)

Plot	1975		1976		1977		Average	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3N	NH_4-N	NO_3-N
C-SIL	1.36	2.91	1.44	0.71	1.03	1.65	1.28	1.76
C-GR	1.12	2.04	2.30	1.10	1.29	2.42	1.57	1.85
R-GR	0.97	3.52	1.52	6.46	0.94	2.57	1.14	4.18
N-SIL	0.88	3.43	1.39	5.50	[a]	[a]	1.14	4.47
N-GR	1.33	4.73	1.83	1.06	1.33	3.49	1.50	3.09

[a]Fallowed in 1977 water year; 2-year average listed.

increased with an increase in crop residues (*CR*) left on the soil surface after harvest and with a decrease in soil loss (*SL*) by the equation

$$\ln C = -2.26 + 0.51 \ln(CR/SL) \qquad (r^2 = 0.81) \qquad (1)$$

where C is in mg/l and CR and SL are in kg/ha (Fig. 1). Crop residues on the conventional-till plots were not incorporated into the soil until spring, just before planting.

Crop residues were 2190 and 6280 kg/ha for the C-SIL and C-GR plots, respectively (McGregor and Greer, 1982). The 3-year average solution P concentrations and losses were about 3 times greater from C-GR (significantly different at the 0.01 level) than from C-SIL (Tables III and VI). The greater concentrations and losses from C-GR were attributed, principally, to the release of P from crop residues (0.05 gP/kg corn stover) left on the soil surface between harvest and spring tillage. The 3-year average runoff from C-SIL and C-GR was similar (Table II).

Plant nutrient losses in the sediments and the corresponding solution losses are given in Tables V and VI. Total losses of N and P (sum of solution and sediment) were greater from conventional tillage than from conservation tillage. Sediment N and P losses were significantly greater (0.01 level) from conventional tillage than from conservation tillage (Tables V and VI), even though concentrations of *TKN* and *STP* on a mass basis — milligrams of N and P per kilogram of sediment (mg/kg) — were significantly greater (0.01 level) from conservation tillage (Table VII). As expected, this enrichment of sediment N and P was inversely related to soil loss (Fig. 2). The 3-year average enrichment of *TKN* and *STP* is expressed as an enrichment ratio (*ER*) in Table VII. *ER* is the concentration of nutrient in the sediment divided by the concentration in the soil. Cumulative frequency distributions of storm *ER-TKN* and *ER-STP* from C-SIL and C-GR did not differ significantly at the 0.05 level, but the *ER* values from conventional-till differed from those from no-till at the 0.01 level.

TABLE V

Annual total (sum of solution and sediment) N losses (kg/ha) in runoff from corn tillage studies (1975, 1976, and 1977 water years)

Plot	1975			1976			1977			Average		
	NH_4-N + NO_3-N	*TKN*[a]	Sum	NH_4-N + NO_3-N	*TKN*[a]	Sum	NH_4-N + NO_3-N	*TKN*[a]	Sum	NH_4-N + NO_3-N	*TKN*[a]	Sum
C-SIL	4.3	55.5	59.8	2.2	45.4	47.6	2.7	33.3	36.0	3.0	44.8	47.8
C-GR	3.2	39.3	42.5	3.4	45.1	48.5	3.7	19.1	22.8	3.4	34.5	37.9
R-GR	4.5	7.1	11.6	8.0	6.1	14.1	3.5	4.2	7.7	5.3	5.8	11.1
N-SIL	4.3	6.4	10.7	6.9	3.2	10.1	[b]	[b]	[b]	5.6	4.8	10.4
N-GR	6.1	11.0	17.1	2.9	5.1	8.0	4.8	4.3	9.1	4.6	6.8	11.4

[a]Total Kjeldahl nitrogen in sediment.
[b]Fallowed in 1977 water year; 2-year average listed.

TABLE VI

Annual total (sum of solution and sediment) P losses (kg/ha) in runoff from corn tillage studies (1975, 1976, and 1977 water years)

Plot	1975			1976			1977			Average		
	P	*STP*[a]	Sum	P	*STP*[a]	Sum	P	*STP*[a]	Sum	P	*STP*[a]	Sum
C-SIL	0.1	21.7	21.8	0.2	17.5	17.7	0.0	13.0	13.0	0.1	17.4	17.5
C-GR	0.3	15.1	15.4	0.4	17.6	18.0	0.2	7.1	7.3	0.3	13.3	13.6
R-GR	0.5	2.2	2.7	0.7	2.1	2.8	0.3	1.4	1.7	0.5	1.9	2.4
N-SIL	0.7	1.3	2.0	0.8	1.0	1.8	[b]	[b]	[b]	0.8	1.2	2.0
N-GR	1.1	2.2	3.3	1.8	1.6	3.4	0.7	1.3	2.0	1.2	1.7	2.9

[a]Sediment total P.
[b]Fallowed in 1977 water year; 2-year average listed.

TABLE VII

Enrichment of sediment *TKN* (total Kjeldahl nitrogen) and *STP* (sediment total P) concentrations (mg/kg) in runoff from corn tillage studies (average 1975, 1976, and 1977 water years)

Plot	Soil[a,b]		Sediment[b]		*ER*[c]		Number of storms
	TKN	*STP*	*TKN*	*STP*	*TKN*	*STP*	
C-SIL	842 ± 107	477 ± 26	1864 ± 33	724 ± 19	2.2 ± 0.3	1.5 ± 0.1	163
C-GR	998 ± 87	508 ± 22	2122 ± 461	807 ± 153	2.1 ± 0.5	1.6 ± 0.3	159
R-GR	1507 ± 210	549 ± 100	4083 ± 322	1353 ± 130	2.7 ± 0.4	2.5 ± 0.5	107
N-SIL[d]	1595 ± 353	529 ± 57	6254 ± 1727	1563 ± 8	3.9 ± 1.4	3.0 ± 0.3	80
N-GR	1546 ± 120	487 ± 25	8622 ± 4315	2122 ± 506	5.6 ± 2.8	4.4 ± 1.1	126

[a]In 0 to 25-mm soil layer.
[b]±1 standard deviation.
[c]Enrichment ratio; i.e. sediment *TKN*/soil *TKN* and sediment *STP*/soil *STP*; ±1 standard deviation propagated for error in soil and sediment *TKN* and *STP*.
[d]Fallowed in 1977 water year; 2-year average listed.

Reductions in soil loss from conservation tillage were great enough to re duce total (sum of solution and sediment) N and P losses. More than 91% of the total N and P losses from conventional-till was transported by the sediments compared with about 60% from N-GR (Table VIII). The high percentage of sediment-associated total P losses from conventional-till is expected (McDowell and Grissinger, 1976; Burwell et al., 1977; Alberts et al., 1978; McDowell and McGregor, 1980).

SUMMARY AND CONCLUSIONS

Studies conducted for 3 years in north Mississippi on loessial fragipan soils indicated that, with conservation tillage, corn can be grown on these highly

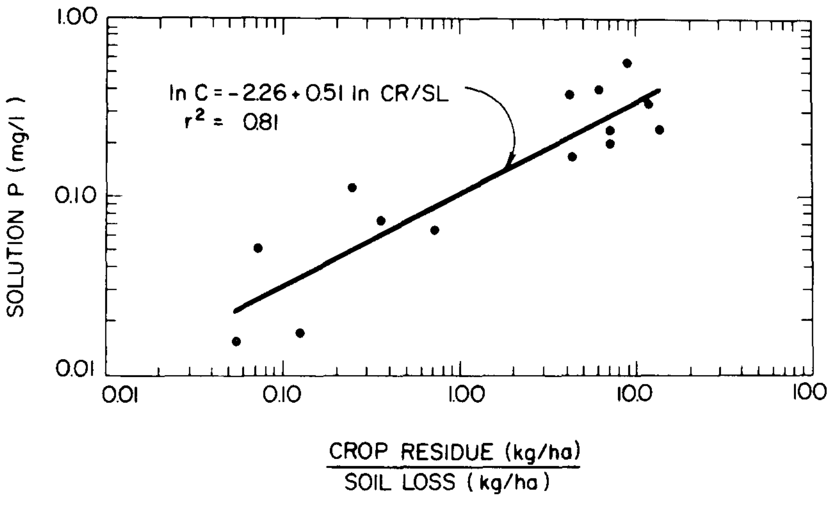

Fig. 1. Annual solution P concentrations (C, mg/l) in runoff as a function of crop residues (CR, kg/ha)/soil loss (SL, kg/ha).

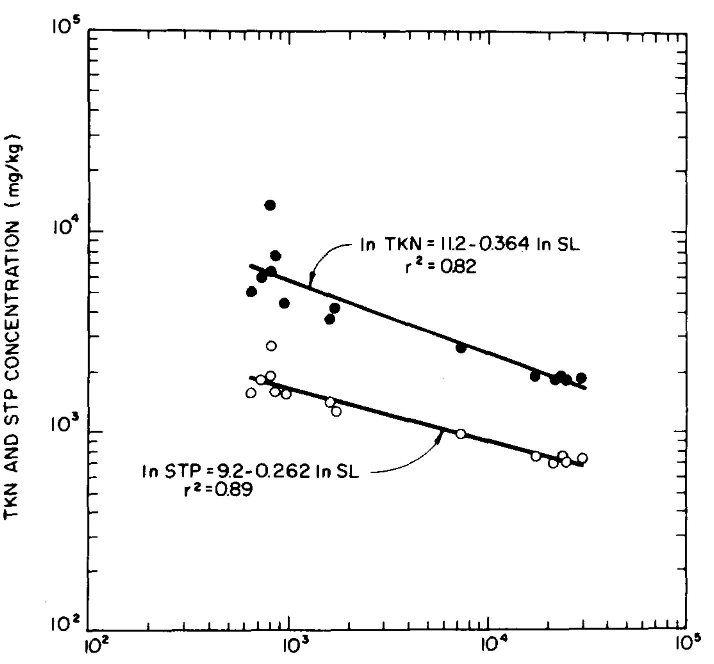

Fig. 2. Annual total Kjeldahl nitrogen (TKN) and sediment total P (STP) concentrations (mg/kg) in runoff as a function of annual soil loss (SL, kg/ha) from conventional and conservation tillage.

TABLE VIII

Percentage of total (sum of solution and sediment) N and P losses transported by solution and sediment (average 1975, 1976, and 1977 water years)

Plot	N		P	
	Solution	Sediment	Solution	Sediment
C-SIL	6.4	93.6	0.6	99.4
C-GR	9.0	91.0	2.3	97.7
R-GR	47.9	52.1	20.5	79.5
N-SIL	53.9	46.1	39.1	60.9
N-GR	40.2	59.8	41.6	58.4

erodible soils with reduced soil loss and total (sum of solution and sediment) N and P losses. Soil losses from corn grown for grain were reduced more than 92% by reduced and no-till practices than with conventional tillage. Corresponding total losses of N and P were reduced about 70 and 80%, respectively.

Less than 10% of the N and P losses from conventional-till was transported in solution; the remainder was transported by the sediments. Both the percentage and amount transported in solution from conservation tillage was much greater. For example, only 9 and 2% of the total N and P, respectively, was transported in solution in runoff from conventional-till corn grown for grain, compared with about 40 and 42%, respectively, from no-till. This increase in the percentage of total N and P transported in solution from conservation tillage was attributed to the higher concentrations of solution N and P in runoff.

Solution P concentrations were significantly greater in runoff from conservation tillage than from conventional tillage. The 3-year discharge-weighted solution P concentrations from no-till corn grown for silage and grain were 10.8 and 4.4 times greater, respectively, than from conventional-till silage and grain. The higher concentrations of solution P in runoff from corn grown for grain was attributed, principally, to the release of P from crop residues. Solution P concentrations increased with increased crop residues left on the soil surface after harvest.

Conservation tillage reduced total (sum of solution and sediment) plant nutrient losses, even though soluble N and P concentrations were greater than with conventional tillage, and sediments were enriched severalfold in N and P. Total losses of plant nutrients were reduced by conservation tillage because of the significant reduction in sediment concentrations in runoff.

The results of this study illustrate the potential conservation benefits of reduced-till and no-till practices to control soil and total plant nutrient losses. The impact of higher concentrations of soluble P in runoff from conservation tillage on downstream receiving waters must be weighed against the reductions in sediment and total plant nutrient losses and in losses of valuable topsoil.

ACKNOWLEDGEMENTS

We thank K.L. Dalton, R.W. Darden, J.D. Greer, G.E. Gurley, and M.E. Ryan for their technical assistance.

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